Shape Optimization of Cochlear Implant Electrode Array using Genetic Algorithms

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Abstract–Finite element analysis is used to compute the current distribution of the human cochlea during cochlear implant electrical stimulation. Genetic algorithms are then applied in conjunction with the finite element analysis to optimize the shape of cochlear implant electrode array based on the energy deposited in the spiral ganglion cells region. The goal is to improve the focus of electrical energy delivered to the spiral ganglion cells in the human cochlea, thus, reducing energy wasted and improve the efficiency and effectiveness of the cochlear implant system.

Index Terms–Finite element method, genetic algorithm, cochlear implant, electrode array.

I. INTRODUCTION

Recently, genetic algorithms (GA) [1] have been applied successfully to many disciplines. GA has some advantage over the traditional gradient method: they are a class of global optimization algorithm and they do not require computation of the derivatives or gradient of the function. GA has been applied to optimize electromagnetic devices [2] optimization problems. In this paper, GA is coupled with finite element analysis to optimize the shape of the cochlear implant electrode array to improve the efficiency of the cochlear implant system.

Cochlear implant (CI) [3] is a system designed to functionally replace the human cochlea for the severe to profound hearing impaired patients. Sound energy is converted to electrical signal and processed through a speech processor (Figure 1). The electrical signal is then delivered via a headpiece or antenna to the electrode array implanted in the inner ear. Specifically, the energy is then channeled to the different spiral ganglion cells and to the brain via the hearing nerve. Clinically, CI is found to be quite effective in restoring hearing to hearing impaired patients. One critical aspect of the CI system is the electrode array which is used to delivered the electrical energy to the spiral ganglion cells, the hearing nerves. In this project, genetic algorithm is coupled with finite element analysis to optimize the shape of the CI electrical array to improve the energy focus of the CI system.

While boundary element method was used to study the electrical potential distribution pattern in cochlea [4], it was studied using an axisymmetric model (2.5D). And currently there is no study available in the literatures for CI electrode shape.

II COCHLEAR IMPLANT ELECTRODE ARRAY

A typical cochlear implant system consists of a microphone, a speech processor, an electrical signal transmitter/receiver and electrode array as shown in Figure 1. This paper focuses primarily on the electrode array design.

Typically, the electrical stimulation are done in common ground mode, monopolar mode and bipolar mode. Since bipolar mode allows better focus of the electrical energy, we will study the CI electrode array in bipolar mode only.

A typical CI electrode array in bipolar mode is shown in Figure 2. Notice the spiral ganglion cells is located near the electrode pair. The electric conduction analysis is performed using finite element analysis. The electrical energy deposited in the spiral ganglion cells is defined as the objective function in the genetic algorithm.

The CI electrodes are shaped by its boundary nodes. The coordinates of the boundary nodes are represented by binary codes. GA can then be used to search the binary codes which represent the coordinates of the boundary nodes (and shape of the electrodes) for optimum values in terms of the objective function.

The electrode shape will be given certain constrained to reduce the search space. Figure 3 shows the flowchart of how the electromagnetic analysis is coupled with the genetic algorithm. Figures 4 - 6 show the current distribution of the various electrode and dielectric partition configurations. These can be used as initial conditions for the genetic algorithm.

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Abstract

Subject Terms

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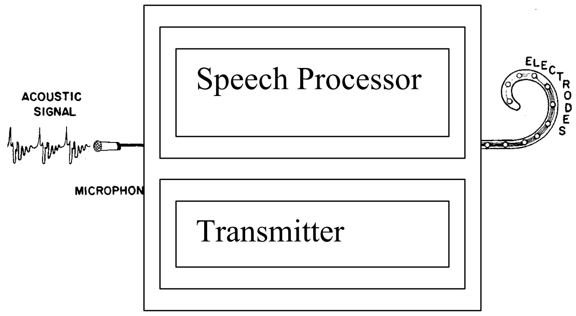

Figure 1 A typical cochlear implant system which consists of a microphone, a speech processor, transmitter/receiver, and electrode implanted inside the human inner ear.

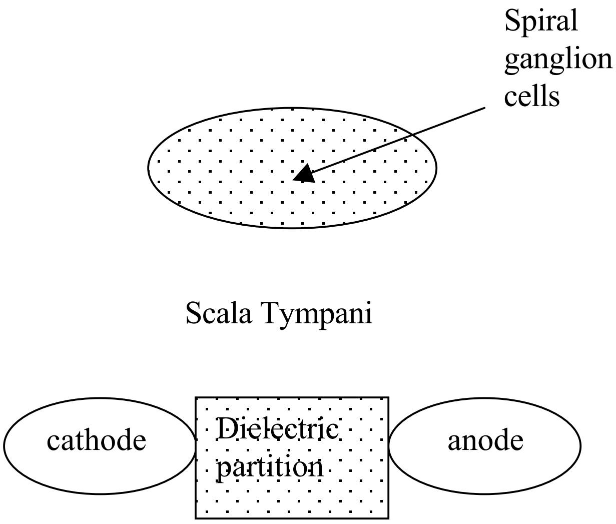

Figure 2 A simplified model of cochlear implant electrode array in bipolar mode. The spiral ganglion cells region is used to compute the electromagnetic energy which is used as the objective function in the genetic algorithm.

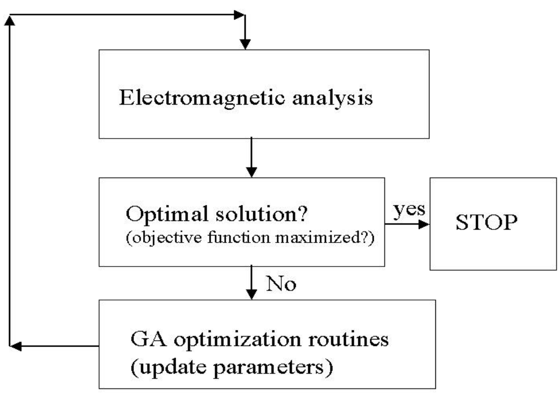

Figure 3 Flowchart showing how the finite element analysis and genetic algorithm are coupled together.

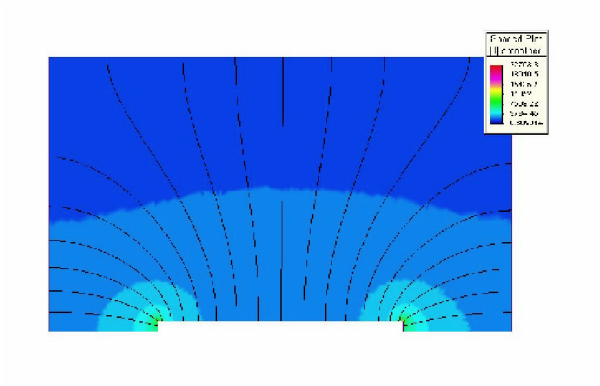

Figure 4 Current density distribution is shown for the case of planar electrodes and flat dielectric partition.

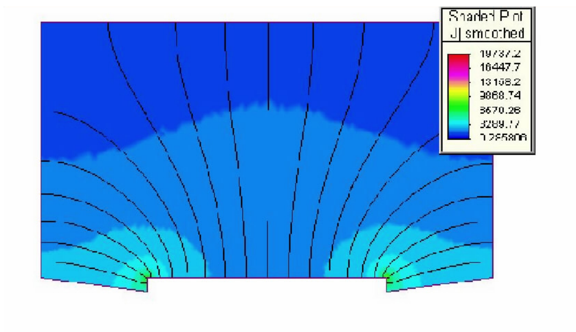

Figure 5 Current density distribution is shown for the case of elevated planar electrodes and flat dielectric partition.

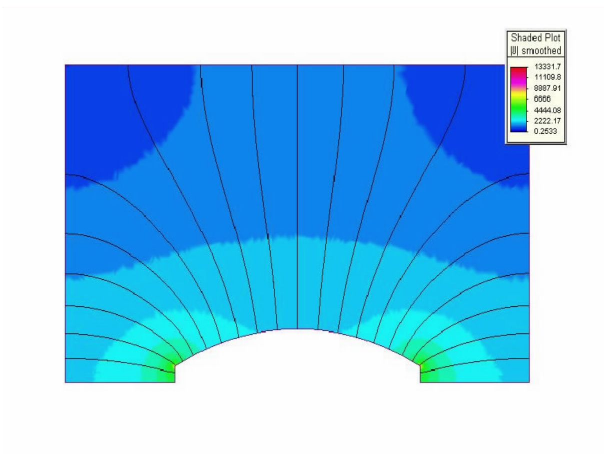

Figure 6 Current density distribution is shown for the case of planar electrodes and curved dielectric partition

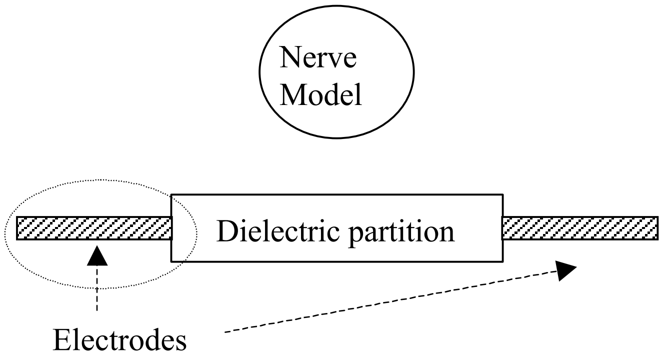

Figure 7 The dielectric partition and electrodes of the CI are shown. The electrodes can be shaped so that maximum energy is deposited into nerve model area.

NO.	Bit String	F(t)	Average E Field
1	0101010000110010	5432	2.111
2	0101001000110000	5230	1.956
3	0100001100100101	4325	1.420
4	0100001100100001	4321	1.407
5	0101000100100011	5123	1.910
6	0011010001010101	3455	0.983
7	0101010100010010	5512	2.229
.			
.			
M	0111010001010000	.	.

Table 1 Bitstrings and their objective functions and average E field are given for a generation in the GA scheme.

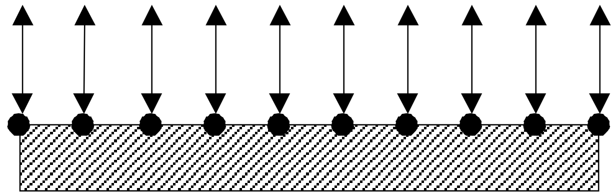

Figure 8 The electrode enclosed by the dashed line oval as shown in Figure 7. At each finite element node on the electrodes, it is freely allowed to move vertically to maximize the electromagnetic energy deposited in the nerve cell model.

NO.	Bit String	F(t)	Mean eField	Status
1	0101010000110010	5432		Old
2	0100001100100101	4325		Old
3	0001001000110011	1233		New
4	0101000100100011	5123		Old
5	0011001000010010	3212		New
6	0001001001010011	1253		New
7	0010001101010001	2351		Old
.				New
.				New
M				Old

Table 2 The new and old generations of shape configuration with their objective and average E field.

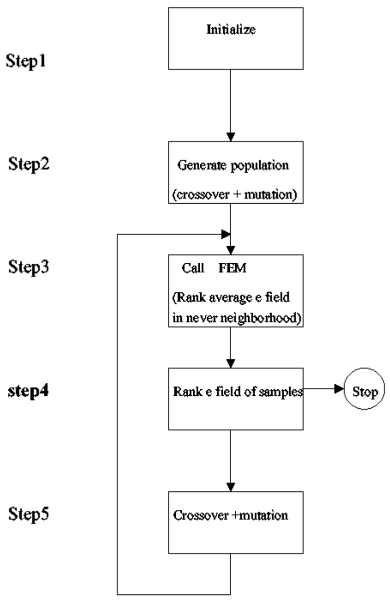

Figure 9 Flowchart of genetic algorithm coupled with electromagnetic analysis based on finite element method.

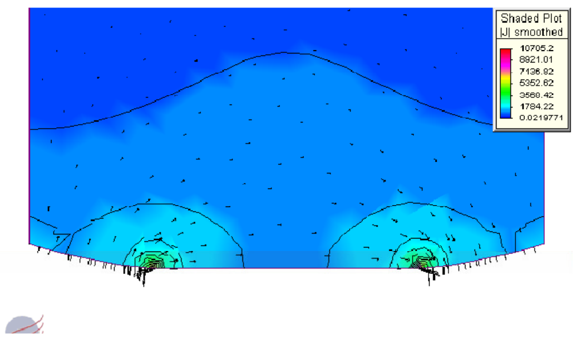

Figure 10 GA optimized electrode pair and its current distribution.

While it is possible to design the electrode shape by try and error, it will be much more efficient to optimize the electrode shape by genetic algorithm (GA) method. Here the objective is the electromagnetic energy deposited in the nerve cell area. The GA scheme will maximize the energy deposited in the nerve cell (Figure 7). In order to shape optimize the electrodes, we let the nodes on the top surfaces of the two electrodes to be free to move vertically (Figure 8). Their coordinates are represented in the form of chromosomes or bitstrings (Table 1).

In each generation, 100 samples of different shape configuration are generated and simulated (Figure 9). The average E field in the nerve cell region is obtained for each shape configuration.

This average E field is used to compute the objective function. The objective function of each sample are ranked (Table 1). The top half are kept whereas the lower half are eliminated. The bitstrings of the top half are used to generate the missing half of the samples for the next generation by crossover [1] (See table 2). Table 2 shows the ranked result of the old generation and the new generation. When the solution converges, the algorithm stops and the optimized solution is obtained (Figure 10)

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